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Solute Spreading in Variably Saturated, Spatially Heterogeneous Formations: The Role of Water Saturation and Soil Texture

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Solute spreading provoked by the spatial heterogeneity in the soil hydraulic properties, and expressed in terms of the macrodispersion tensor, D, plays an important role in solute transport on the field scale. Under variably saturated flow conditions, quantification of D is rather complicated inasmuch as the relevant flow parameters, which depend on the formation properties, depend also on flow-controlled attributes in a highly nonlinear fashion, which, in turn, depends on the soil texture of the formation. The situation may be further complicated when the formation contains inclusions of different soil material and its hydraulic properties follow a bimodal distribution.
The present talk focuses on the quantification of D in bimodal, heterogeneous, variably saturated formations, viewed as mixtures of two populations (background soil and embedded soil) of differing spatial structures. Two distinct cases are considered; in the first case, the texture of the embedded soil is finer than that of the background soil, while the second case conists of the reverse situation.
First-order, Lagrangian stochastic analyses of vadose zone transport were used to invesigate the combined effect of the texture of the embedded soil and the mean pressure head on solute spreading in these formations. Results of the first-order analysis suggest that the embedded soil material may act as a capture zone for the solute particles, and, consequently, may enhance solute spreading in a manner which depends on both the texture of the embedded soil and the mean pressure head. In the first case, when the formation is relatively wet, the capture zone stems from the fine-textured embedded soil. In the second case, when the formation is relatively dry, the capture zone stems from coarse-textured embedded soil associated with very low unsaturated conductivity, which, in turn, may divert the flow into preferential flow paths around the coarse-texture, soil inclusions. Important finding of the first-order analysis suggests that features of solute transport associated with the two different formations exhibit a crossover behavior and that the mean pressure head associated with the crossover may be estimated from the asymptotic D associated with the two formations.
The applicability of the results of the first-order analysis to more realistic conditions was tested by a series of numerical simulations of flow and transport in 3-D, heterogeneous, bimodal, variably saturated formations, considering relatively simple, steady-state flow, and more complicated, transient, non-monotone flow originating from periodic influx and water uptake by plant roots. For the steady-state flows, results of the simulations were in qualitative agreement with the results of the first-order analysis. For the more realistic flow regime, the results of the simulations suggested that the difference between the responses of the two different bimodal formations might decrease substantially, similar to the situation in steady-state flow associated with mean pressure head at which a crossover occurs.